Comparison of Blockage Widths of Ideally Hard Cylinders of Different Cross-Sectional Shapes

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Introduction

In some applications the electromagnetic waves radiating from or being received by an antenna are obstructed by some mechanical structure. If the structure is part of or close to an antenna, the obstruction may represent aperture blockage causing increased sidelobes and reduced gain of the antenna. For example, the blocking structures can be struts or masts supporting the feed in reflectarrays or in reflectors. Usually in antennas, the direction of the incident wave is known, so the struts can be designed to reduce the blockage for a given direction of incidence.

The extensive previous paper [1] showed how field blockage from thin struts can be reduced for any polarization by making use of an oblong cross section and electromagnetically hard surfaces. The hard surface is ideally a perfect electric conductor (PEC) for TE-case (E-field orthogonal to the cylinder axis) and a perfect magnetic conductor (PMC) for TM-case (H-field orthogonal to the cylinder axis). The oblong cross-sectional shape was chosen to be rhombic in [1], and no other oblong shapes have been investigated in the literature. Therefore, it is the purpose of the present paper to investigate different oblong cross-sectional shapes for blockage reduction of cylinders with ideally hard surfaces. We choose to study normal incidence on PEC (realized as metal) cylinders for TE-case, but the results are valid also for TM-case and PMC cylinders and for dual polarization for ideally hard dual-polarized struts. Reduction of field blockage can also be referred to as making objects invisible to RF. Invisibility means to reduce field blockage, i.e. to reduce the forward scattered field. The forward scattered field is traditionally characterized in terms of an induced field ratio (IFR) [2-3]. It is even better to characterize blockage in terms of an equivalent blockage width W_{eq} that is proportional to the product of the IFR and the physical width W [1]. Using this, it is easy to compare objects with respect to their invisibility. The equivalent blockage width is the width of the equivalent hypothetical shadow that gives the same forward scattered field.

The smallest blockage width is obtained for the hard surface, because this provides the correct boundary conditions for waves to propagate as undisturbed as possible around the strut.

For opaque objects, the blockage width becomes at high frequency equal to the physical width. The blockage width becomes by the definition a complex value, where both the real part and the absolute value are representative for characterizing invisibility. The total scattered power integrated over all directions is proportional to the real part of the equivalent blockage width W_{eq} [4]. The blockage loss due to support struts in a reflector is proportional to the real part of W_{eq}, i.e., the reduction in dB of the directivity of the antennas due to the blockage. The high sidelobe level due to the struts appearing near the main lobe is proportional to the absolute value of W_{eq} as explained in [5]. From this it is evident that it is

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more important to reduce the real part of the equivalent blockage width than its absolute value, as the real part determines the directivity reduction and represents the scattered power averaged over all directions around the cylinder.

The equivalent blockage width is readily computed by considering a plane wave incident on an infinitely long strut, which is a two dimensional scattering problem. Note that for all the results in the paper the angle of incidence of the wave is fixed and normally to the cylinder axis. The incidence is from left to right for the cross sections shown in the figures. The cross sections have a width normal to the direction of wave propagation and a length along it. The present results have been computed by using the FDTD software CST Microwave Studio with periodic boundary conditions as explained in [6]. This means that the strut is assumed to be infinitely long. The studied blocking objects have physical widths W smaller than or comparable to the wavelength λ.

In the simulations we used physical cross sections of all cylinders of W=54.2 mm, and we found the equivalent blockage widths in the frequency range 0.1 to 20 GHz. However, the results are presented as a function of the physical width W/□.

Cylinders of different cross-sectional shapes

We first compute results for ideally hard cylinders of different cross sectional (cylinder and rectangle) shapes with the same physical width. The wave is incident from the left, hitting the narrow side of the strut with the E-field orthogonal to the edge for TE case. The real part and absolute value of the equivalent blockage width W_{eq} of cylinders with circular, rhombic, star-shaped and thin rectangular cross sections are shown in Figure 1. The latter is oriented orthogonal to the direction of wave propagation and has the same width as the other cylinders. The thickness of the rectangular cross section is 1 mm, and this is the same for both the transverse and longitudinal part of the star-shaped cross section. The results show that the rhombic cross section of the strut has the smallest real part of W_{eq} when the physical width is comparable to the wavelength, whereas the star shaped and thin rectangular cross section is best when the physical cross section is narrower than approximately 0.2λ.

Figure 2 present the equivalent blockage widths of cylinders with rhombic cross sections. The results show that a longer rhombic cross section have a smaller blockage width except for very narrow widths in terms of frequency. This is in agreement with the results of Figure 1 that the transverse strip (thin rectangular cross section) is the best for narrow cross sections.

Optimized cross-sectional shape

The equivalent blockage width W_{eq} of metal struts can be reduced significantly if the shape of the strut cross section is numerically optimized. An initial study of what can be achieved has been performed in [7]. Figure 3 presents the equivalent blockage width of three cross sections that are identical in terms of physical width W=54.2 mm and length L=108.4 mm. One of these has been numerically shape-optimized for lowest average blockage width over a given frequency, for a fixed physical width and length. This frequency range corresponds to the fixed physical width being between 0.08 and 0.17λ. In comparison with Figure 2 we can observe that the strut with the rhombic shape yields an equivalent blockage width that is larger compared with the optimized shape when the physical width is smaller than 0.2□, despite the fact that the physical width and length of the two cross sections are identical. On the contrary, when the physical width is comparable to the wavelength, the blockage is smaller with the rhombic strut than the optimized strut.

Conclusions

We have computed the equivalent blockage width of ideally hard cylinders of different cross sections. We have shown that the oblong cross section is best when the physical width is larger than about 0.2λ, whereas for narrower cross-sections the transverse thin rectangular cross-section is best. The latter can be strengthened by a star-shaped cross section, without significant change in the blockage width. The latter was found as a result of numerical optimization. The optimized oblong shape is explained by a smooth transition of the waves past the cylinder, which is facilitated by the GO characteristics of the hard surface [8]. The thin rectangular cross section is explained as a quasi-static solution. The cross-section is so narrow in terms of wavelengths that transverse currents cannot be induced. The star-shaped cross-section works like the transverse rectangular cross-section, because the orthogonal rectangular part making up the two other arms of the star are invisible to the wave because of their small thickness.

It must be emphasized that we have treated ideally hard cylinders. This makes the results valid for metal cylinders and TE-case. The performance for TM-case depends on the realization of the PMC surface, but the results can be seen as typical performance at the center frequency. The bandwidth will normally be small, but can be up to 20-30% when the artificial magnetic conductor is realized by dielectric coatings as shown in [1].

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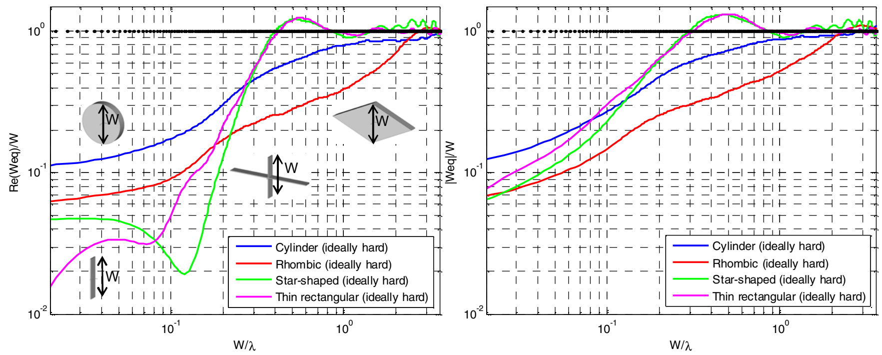

Figure 1. Equivalent blockage width of ideally hard cylinders with different cross-sectional shapes.

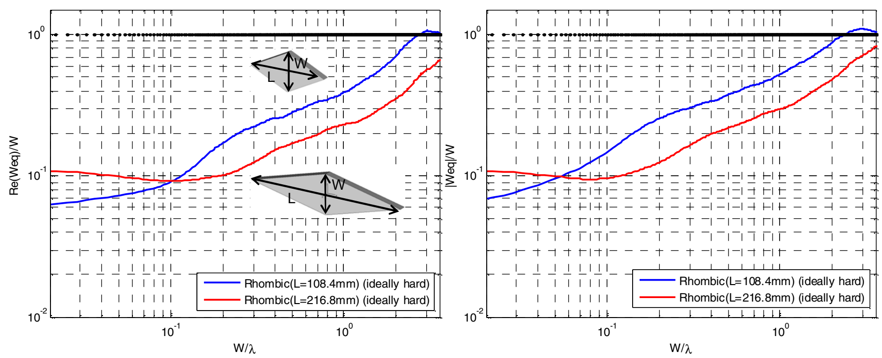

Figure 2. Equivalent blockage width of ideally hard cylinders with rhombic cross section of widthW, L=2W and L=4W.

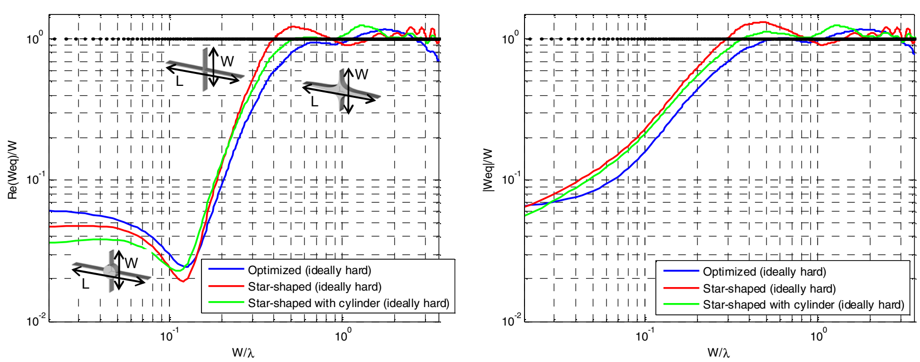

Figure 3. Equivalent blockage width of ideally hard cylinders with three different star-shaped cross-sections (width W, length L=2W).